# A New Microwave Triode: Its Performance as a Modulator and as an Amplifier

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This paper describes a microwave circuit designed for use with the 1553-416A close-spaced triode at 4000 m.c. It presents data on tubes used as amplifiers and modulators and concludes with the results obtained in a multistage amplifier having 90 db gain.

## Introduction

MICROWAVE repeaters are of two general types: those that provide amplification at the hase-band or video frequency and those that amplify at some radio frequency. Of the latter there are two types: those that involve no change in frequency and those that do involve a change in frequency, that is, the radiated frequency is different from the received frequency. The Boston-New York link[1] is of this last type as is also the New York-Chicago link. This paper deals chiefly with a discussion of the application of the close-spaced triode[2] in a repeater of the type to be used between New York and Chicago.

A hlock diagram of this type of repeater appears in Fig. 1. The received signal comes in at a frequency of, say, 3970 mc. It is converted to some intermediate frequency, say 65 mc, in the first converter which is associated with a heating oscillator operating at a frequency of 3905 mc. After amplification at 65 mc it is converted in the modulator hack to another microwave frequency 40 mc lower than the received signal and then it is amplified by the r.f. amplifier at 3930 mc and transmitted over the antenna pointed toward the next repeater station. Our attention will be focussed upon the performance of the close-spaced triode in the transmitting modulator and in the r.f. power amplifier in this type of repeater.

The close-spaced triode was assigned the code number 1553 during its experimental stage of development and, with subsequent mechanical improvements, it became the 416A. Some of the data reported herein were taken on one type, and some on the other; references to hoth the 1553 and 416A tubes will he noted throughout the text. The difference in electrical performance was not significant.

An early experimental circuit for the 1553 type tube will be described

* Deceased.

in detail and the performance as amplifier and modulator will be presented. Measurements of noise figure will be included with a discussion of the performance of multistage amplifiers.

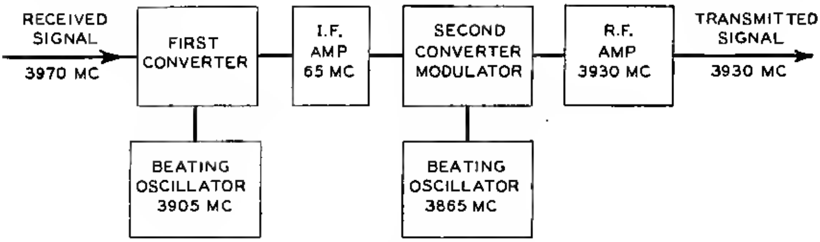


Fig. 1.—Typical microwave repeater.

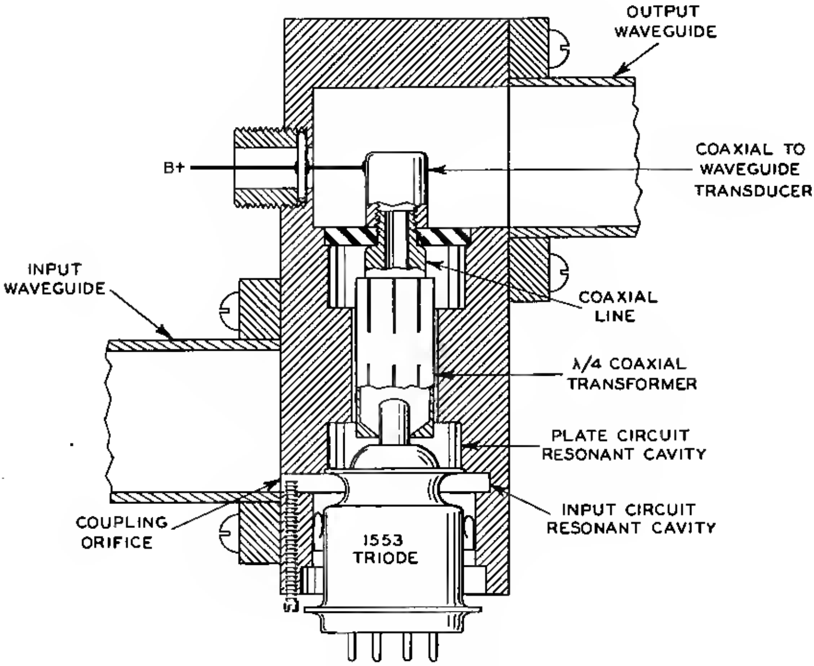


Fig. 2.—Microwave circuit for 1553 triode.

## The Microwave Circuit

The experimental circuit which has to date met with greatest favor consists of cavities coupled to input and output waveguides, as shown in Fig. 2. The grid, of course, is grounded directly to the cavity walls and separates the input cavity from the output cavity. An iris with its orifice

couples the input waveguide to the input cavity and is tuned by a small trimming screw across its opening. The metal shell of the base of the tube makes contact to the input cavity through spring-contact fingers around its circumference and forms a part of the input cavity. The cathode and its by-pass condenser, located within the envelope, complete the input circuit cavity. The heater and cathode leads, hrought out through eyelets in the base of the tube, are isolated from the microwave

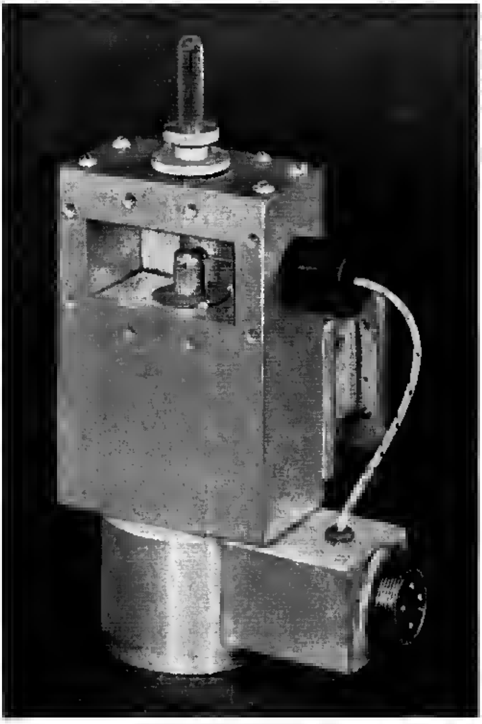

Fig. 3.—Model eleven microwave circuit for the close-spaced triode looking into the output waveguide.

energy in the input cavity by means of the internal by-pass condenser. When the tube is used as a modulator, this by-pass condenser acts as a portion of the network through which the intermediate frequency signal power is fed onto the cathode.

The output circuit cavity is coupled to the output waveguide through a coaxial transformer, a coaxial line and a wide-band coaxial-to-waveguide transducer. The output cavity is bounded by the grid, the coaxial line outer conductor, the radial face of the quarter-wave coaxial transformer

and the sealed-in plate lead of the tube. The plate impedance of the tube is transformed by the resonant cavity to a very low resistance (a fraction of an ohm) on the plate lead just outside tbe glass seal. The quarter-wave coaxial transformer serves to match this low impedance to the surge impedance of the coaxial line (45 ohms). Coarse tuning is accomplished by moving the slug of the outer conductor; fine tuning by moving the inner conductor. The coaxial line is supported at its end by a dielectric washer. Plate voltage is applied to the tube through a high impedance quarter-wave wire brought out to the low impedance probe through the side wall of the waveguide. Both the modulator and the amplifier used this type of circuit, which we call model eleven.

Fine tuning of the plate cavity is obtained by sliding the inner conductor of the coaxial transformer up and down on the plate lead. This movement is derived through a low-loss plastic screwdriver inserted through the hollow probe transducer; the driving mechanism is housed inside the inner conductor of the transformer, thus isolating the mecbanical design problem from the electrical design problem effectively. The hollow stud at the top of the structure serves two purposes: screwing it into the waveguide introduces a variable capacitive discontinuity which serves to improve the match between the cavity and the waveguide. The length of the hollow plug provides a length of waveguide beyond cutoff which keeps the r.f. energy from leaking out through the plastic tuning screwdriver.

The heater and cathode leads from the tube are housed in a cylindrical metal can and are hrought out through hy-pass condensers to a standard connector. The photograph, Fig. 3, illustrates these features.

The input face of the circuit is illustrated in Fig. 4. The long narrow slot near the base of the rectangular block is the iris opening which couples the input waveguide to the cathode-grid cavity. The single tuning screw provided at the input iris is not adequate to match all of the tubes over the whole frequency band of 500 megacycles; an auxiliary tuner shown at the right of the circuit provides the necessary flexibility. This tuner, descrihed by Mr. C. F. Edwards of the Bell Telephone Laboratories[3], is, in effect, two variahle shunt tuned circuits ahout an eighth of a wavelength apart in the waveguide. Each variable tuned circuit is made up of a fixed inductive post (located off center in the waveguide) and a variable capacitive screw. It is capable of tuning out a mismatch corresponding to four db standing wave ratio of any phase.

As shown in Fig. 5, the tube slides into the bottom of the circuit and the grid flange is soldered to the wall of the cavity with low melting point

solder.† The shell of the tube is grasped by the springy contacts around the bottom of the input cavity. Above the tube the plate lead projects into the cylindrical space which can be adjusted to the desired size by the quarter wave slug seen to the right of the circuit. This makes contact to the walls of the outer cylinder by spring fingers on each end. Contact to the plate lead is then made through the movable slotted inner conductor, seen on the extreme right of Fig. 5.

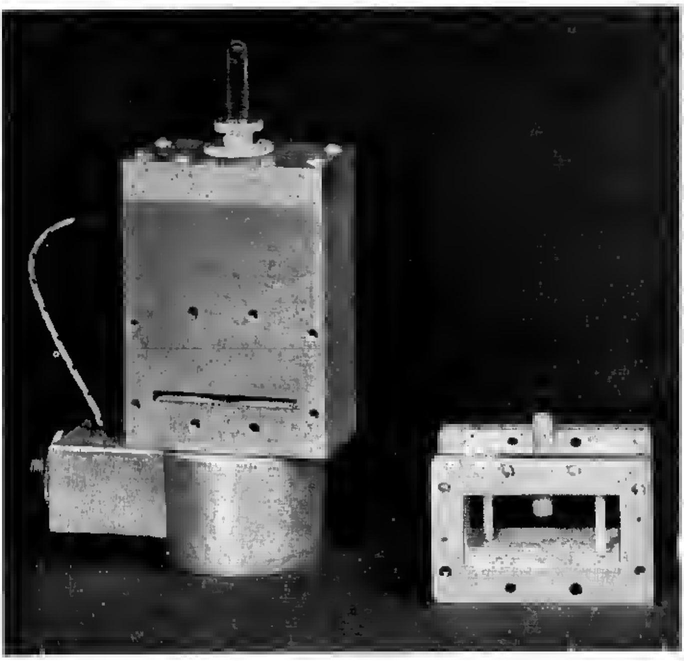

Fig. 4.—The input face of the circuit.

Figure 6 gives an exploded view of the details of the circuit, showing the simplicity of the construction which permits easy assembly. The guide pin which serves to keep the inner conductor of the transformer from rotating as it slides up and down on the plate lead during the tuning process can be seen on the third detail to the right of the main block. Also there is provision for external resistive loading to be introduced into the plate cavity through the small square holes in each side of the block. A screw mechanism adjusts the penetration of the loading resistive strip into the

† The early experimental tubes were soldered into the circuits. Chiefly through the efforts of Mr. C. Maggs and Mr. L. F. Moose, of B. T. L., who undertook the development of the tube for production by the Western Electric Company, the present 416A tubes come with a threaded grid flange to facilitate replacement.

plate cavity to provide for a limited adjustment of the bandwidth of the circuit. These are not always used, however, and most of the data to be presented here are for the condition of no external resistive loading.

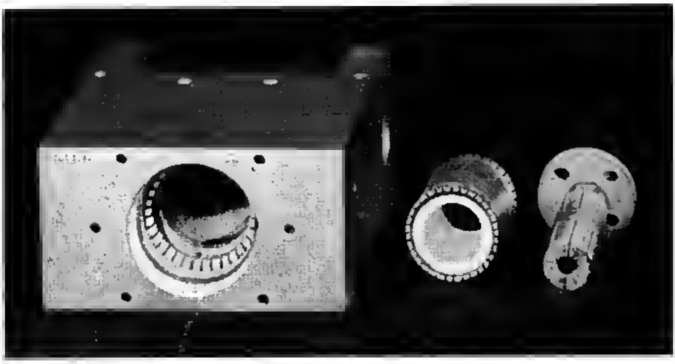

Fig. 5.—Bottom view of circuit.

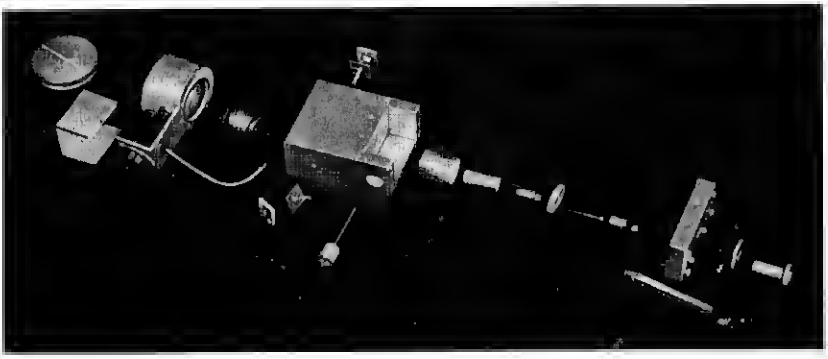

Fig. 6.—Exploded view of details.

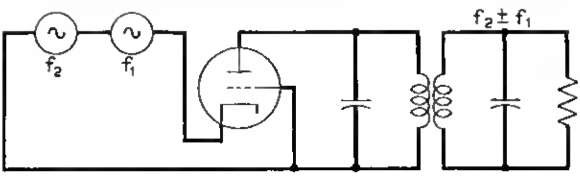


Fig. 7.—Elementary grounded grid converter schematic.

## Modulator

The grounded grid transmitting converter shown schematically in Fig. 7 includes the two generators, a microwave beating oscillator, $f_2$, and an intermediate frequency signal, $f_1$, which impress voltages on the cathode,

the grid itself being grounded. The output circuit in the plate is tuned to the sum or difference frequency, $f_2 \pm f_1$.

By-pass condensers, traps and filters for other frequencies present in the modulator must he considered. Besides the beating oscillator and the signal, their sum and difference frequencies appear in both the input circuit and the output circuit and of course bias voltage on the cathode and plate voltage on the plate must he applied. Some of the traps and by-pass condensers which influence the converter performance are indicated in Fig. 8. It is obvious that microwave energy should be kept from flowing into the i.f. signal circuit and vice versa if the highest conversion gains are to be obtained. Both of these conditions are easily achieved. It is not so readily apparent that the components of the wanted and the unwanted sidebands present in the input circuit must be handled

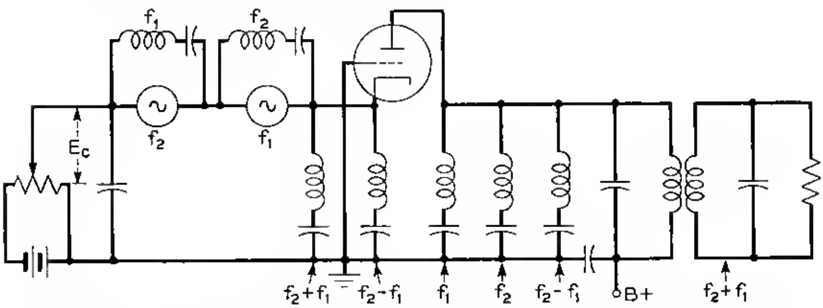


Fig. 8.—Schematic diagram of converter with traps and filters for fundamental frequencies of signal, $f_1$, beating oscillator, $f_2$, and sidebands, $f_2 \pm f_1$.

properly. Of these two, the more important is the wanted sideband and the next figure illustrates just how necessary it is to treat it properly.

The simplest way to keep the wanted sideband component of the input circuit from heing absorbed hy the beating oscillator hranch is to reflect the energy hack into the converter by means of a reflection filter. This reflected energy arrives back at the tuhe and may conspire to reduce the conversion gain of the modulator if the phase is wrong. The phase depends upon the spacing along the waveguide between the tuhe and the filter and Fig. 9 illustrates how badly the gain is affected when the wrong spacing is used. Data for two different tubes are given which indicate that the correct spacing for one tube may be incorrect for another. It should be pointed out, however, that these two tuhes were early experimental models and that production tuhes hehave more consistently.

The i.f. impedance of the modulator is also affected hy the filter spacing for the wanted sideband on the input. This effect can be utilized to

vary the i.f. impedance by small amounts to achieve a hetter i.f. match, since the proper spacing for best gain is not a critically exact dimension. That is to say, there is a fairly large range of spacings which give good performance as far as conversion gain is concerned so that, as long as the critical distance which gives poor gain is avoided, the i.f. impedance can he adjusted by varying the spacing of the input filter.*

It is important that the i.f. impedance of the modulator he adjusted to match the impedance of the i.f. amplifier which drives it, since any mismatch would cause a degradation of the system performance. In the design of the matching transformer the inductance of the leads, the capacity of the tuhe and hy-pass condenser and the resistance of the elec-

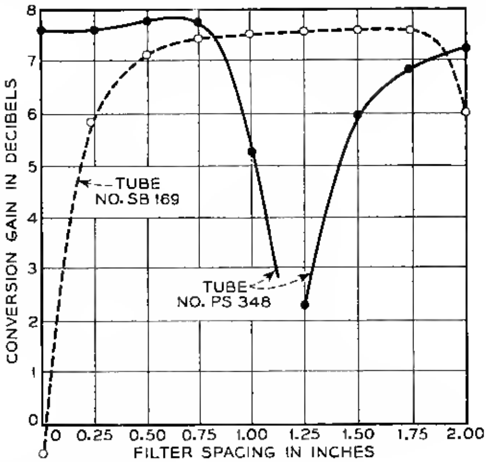


Fig. 9.—Data showing the effect of the spacing of a rejection filter for the wanted side-band in the input circuit.

tron stream were measured at the hase of the tuhe. A hroad-hand transformer was designed and the inductances were thrown into an equivalent $T$ network, therehy utilizing the lead inductance inside the tuhe as a part of the transformer, absorbing it in the $L_2$-$M$ hranch as indicated in Fig. 10. In several experimental tuhes the lead inductance was $.04\mu H$. The impedance match ohtained with such a transformer gave less than two dh *SWR* over a hand from 55 to 75 mc with the loop at the cusp on the reflection coefficient chart characteristic of slightly over-coupled tuned transformers as shown in Fig. 11.

The hroadhand matching of the output circuit of the modulator required a different technique. Not only is this filter called upon to provide a hroad-hand impedance match, hut also it should provide dis-

* The spacing of the input filter also affects the plate impedance in a complicated way.

crimination against the other microwave-frequency components present in the modulator output circuit; consideration of the beating oscillator and

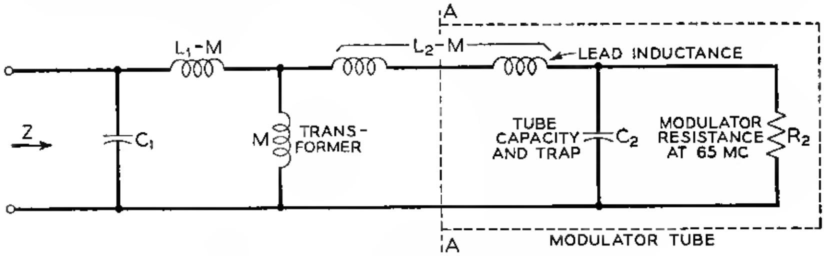


Fig. 10.—Equivalent circuit of modulator at I. F.

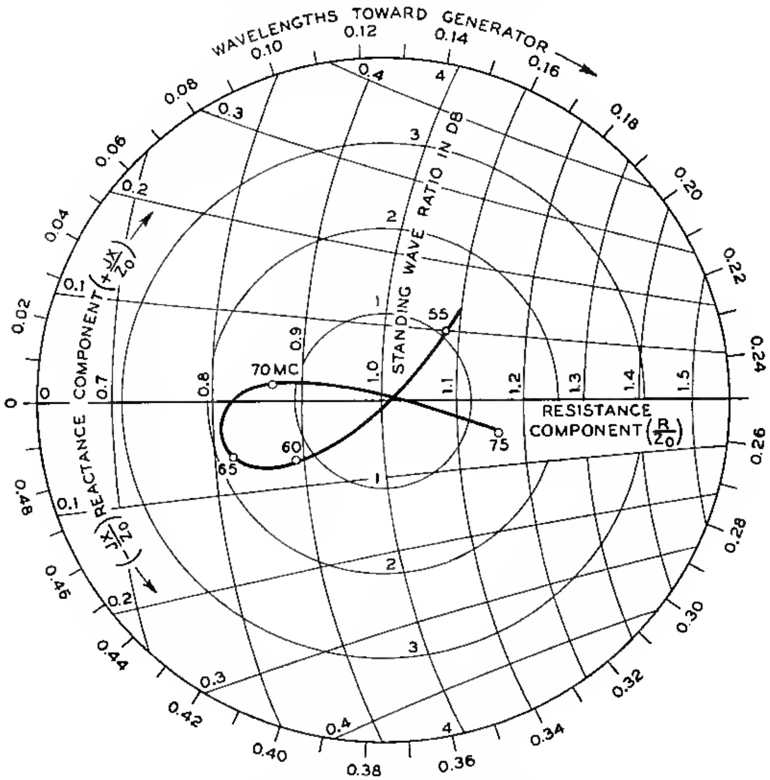


Fig. 11.—Modulator I. F. impedance with transformer.

both sidebands is necessary. The variables at our disposal are the bandwidth of the modulator output circuit and the number of cavity resonators which follow it. The desired quantities are the specified transmission

handwidth and the attenuation required at the beating oscillator frequency. With two equations and two unknowns, the maximally-flat filter theory was applied to the circuit shown schematically in Fig. 12.[4] This indicated that an output circuit handwidth of 84 mc (to the three dh loss points), associated with two external resonant branches having bandwidths of 42 and 84 mc respectively, were needed to ohtain a 20 mc flat hand with 30 db suppression of the beating oscillator.

Such cavities were designed and attached to the output of a modulator whose handwidth had been adjusted hy means of small resistive strips.

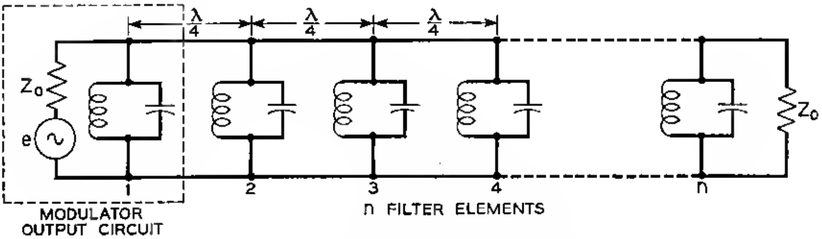


Fig. 12.—Sideband filter in waveguide.

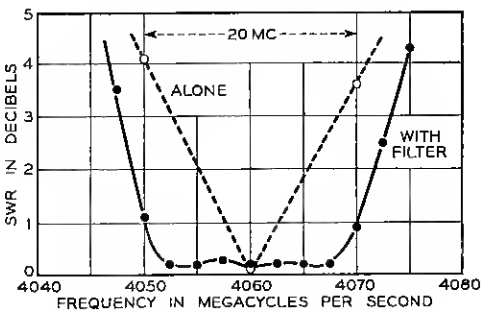


Fig. 13.—Output circuit impedance match.

The resulting impedance match gave a standing wave ratio of less than one db over a 20 mc hand (the plate circuit alone without the filter was only about 5 mc wide to corresponding points) as shown in Fig. 13, and the beating oscillator power at the output of the filter was less than one tenth of a milliwatt, corresponding to 33 db discrimination.

The requirements and specifications for this particular experimental model do not necessarily reflect out present thoughts upon the requirements for any particular microwave radio relay system; they are presented here in some detail to indicate how certain specifications can be met, rather than to express what those specifications should he.

Other factors which influence the performance of the 416A modulator

are the plate voltage and the beating oscillator drive. The beating oscillator power affects the low level gain only slightly but has quite an effect on the gain at high power levels, that is, when the output power becomes comparable with the beating oscillator power. It is seen in Fig. 14 that compression becomes noticeable when the output power approaches within ten db of the beating oscillator driving power.

Varying the plate voltage on the modulator from 150V to 300V had little effect upon the conversion gain at low levels, but more power output

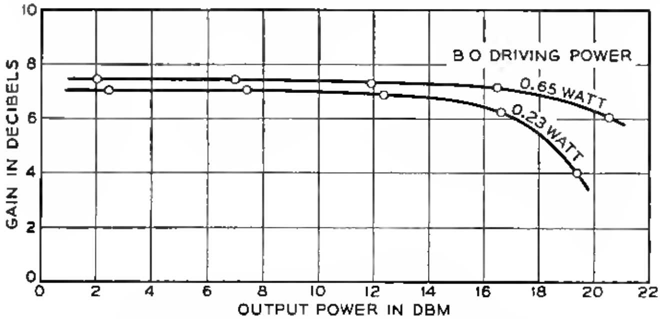


Fig. 14.—Modulator compression data for tube #PS62.

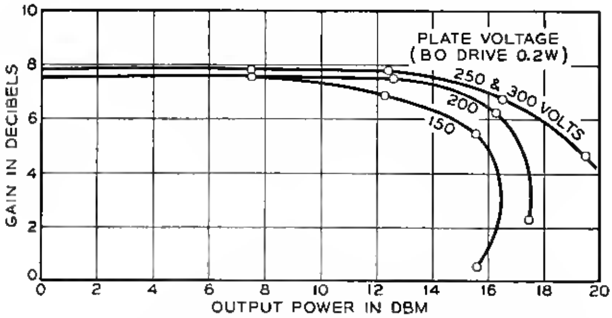


Fig. 15.—Modulator compression data for tube #PS348.

was obtained at the higher voltages. At 15 dbm power output, very little difference between 200V and 300V was observed, but at 150 V the gain was down two db, as shown in Fig. 15.

Fig. 16 shows the compression data for seven early experimental tubes, used as modulators with 200V on the plate, 14 ma cathode current, and 200 mw of beating oscillator drive. Half of these tubes had over seven db low level gain and only slight compression at power output levels of 13 dbm. The two poorest tubes would probably have been rejected before shipment, according to present standards of production. Each of the seven tubes was matched in impedance on the r.f. and i.f. inputs and also

on the r.f. output. The curves represent unloaded gain; no external loading was added to increase the bandwidth.

The performance of the close-spaced triode when used as a modulator appears to be superior in some respects to that of the silicon crystal modulators which are used in the New York-Boston microwave relay system.[1]

Single tubes had from 5 to 9 dh gain compared with from 8 to 11 db loss for the crystals for corresponding power outputs. To get this performance the beating oscillator drive was only 200 milliwatts, compared with ahout 700 milliwatts for the crystal modulator. This reduction in r.f. power requirements means considerahle simplification in a repeater.

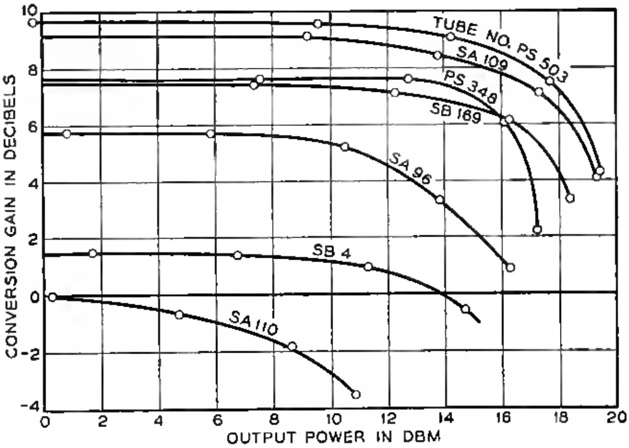


Fig. 16.—Compression data on seven 1553 triodes.
Plate voltage 200V
Plate current 14 Ma
B.O. Power 200 MW
Matched inputs and output

To offset this, the tuhe requires power supplies which are not necessary for the crystals, but low voltage power supplies should be cheap. The bandwidth of the tube modulator, 60 to 80 mc is less than the very wide (500 mc) hand of the crystal modulator hut it is comparable with the band width of the extra i.f. stages needed to drive the crystal modulator. The life of the tuhes, although very little data are available as yet, will probahly be less than the practically indefinite life of the silicon point contact modulators.

## Amplifier

The performance of the close-spaced triode as an amplifier can best be described by referring to its impedance match, gain, transmission bandwidth and compression.

In some of the experimental tubes, bandwidths to the half power points of 21 mc to 250 mc have been measured. Typical of one of the better tubes, though not the best one, are the data contained in Fig. 17. The bandwidth of the input circuit is about twice that of the output circuit, and the SWR slumps outside the band on the low frequency side. The output impedance is more regular, exhibiting the familiar standing wave

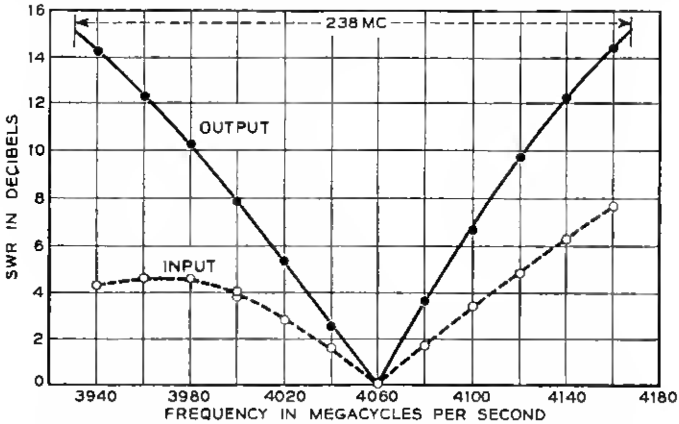


Fig. 17.—Input and output standing wave ratio versus frequency.

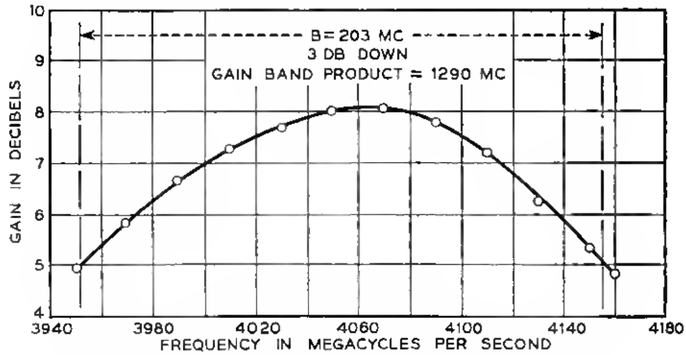


Fig. 18.—Transmission characteristic of a one-stage amplifier.

ratio of a simple single tuned resonant circuit. When the output impedance is plotted on the Smith reflection coefficient chart, the circle which results is also similar to that of a single tuned circuit. This is desirable since it then becomes a simple matter to incorporate the plate circuit in a maximally-flat filter of as many resonant branches as are needed, in the same way that the modulator output circuit was treated.

The transmission bandwidth for this single stage amplifier was 203 mc to the half power points, as shown in Fig. 18. This, with a gain of 8.05 db

at midhand, gave a gain-band product of 1290 mc. The handwidtb of 203 mc was considerably greater than the average for these tuhes. Similar results on 35 experimental tuhes yielded the following averages: Low-level gain 10 db; Bandwidth 103 mc; Gain-hand product 916 mc. The 416-A tuhes produced hy Western Electric Company exhihit comparahle averages witb much less spread; for example, a recent sample of 138 tuhes bad average values and standard deviations as follows:

TABLE I
GAIN AND BANDWIDTH OF 138 W. E. CO. 416-A TRIODES

| | Average | St'd. Dev. |
|---|---|---|
| Low-level gain | 9.9 db | 1.1 db |
| Bandwidth | 110 mc | 9 mc |
| Gain-band product | 1080 mc | 350 mc |

It is indeed gratifying to realize that such a remarkahle tuhe can he produced with such uniformity.

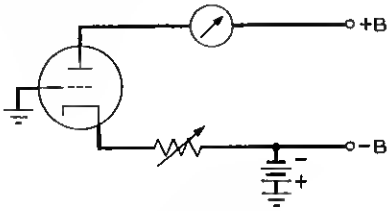


Fig. 19.—Stabilizer circuit.

In operating these tubes, it bas been found that small variations in gain due to power line fluctuations and due to other disturbing influences can he minimized hy using a stabilizing hias network wbich provides a large amount of negative feedhack for the dc. path. This circuit is similar to one proposed by Mr. S. E. Miller of the Bell Telephone Lahoratories for use in coxial repeaters which also use high transconductance tuhes. In this circuit, shown schematically in Fig. 19, a few volts negative are applied to the cathode througb a suitable dropping resistor. In the absence of plate voltage, the grid draws current, being positive with respect to the cathode. When plate voltage is applied, the drop in the cathode resistor tends to hring the cathode nearer ground potential until a stable voltage is reached. The resistor is set to a value which allows tbe desired catbode current to flow and suhsequent variations in $g_m$ or plate voltage then have little effect on the total cathode current.

Maintaining the cathode current constant does have an appreciahle effect on the gain of the tube when operating at high output levels. This is characterized by a decrease in gain as the driving power is increased.

Fig. 20 illustrates this point. The low-level gain of this tube was 12.3 db but when the tube was driven so as to have an output power of 400 mw the gain was only about 3 db. At this point, retuning the circuit to rematch the tube at the high output level increased the gain to about 5 db. Now, returning to low level, the gain was only 10 db. Presumably in between these two points, 5 db at 500 mw output and 12.3 db at less than one milliwatt output, the performance could have been better than either of these two curves shows, i.e., the performance could have been improved by rematching at each intermediate power level.

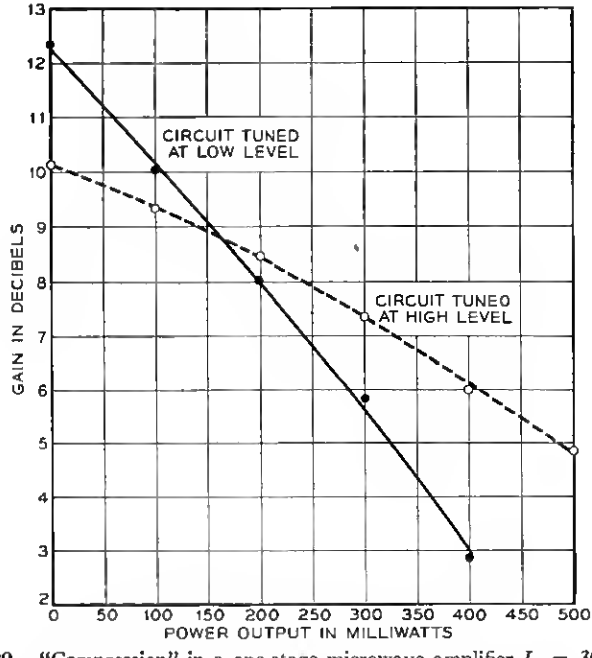


Fig. 20.—"Compression" in a one-stage microwave amplifier $I_p = 30$ ma.

This tube is not representative of all of the tubes tested. It is rather poorer in the spread of the two curves than most. It was picked merely to illustrate that besides a drop in gain also a detuning effect takes place when the driving power is changed. In the example given here the cathode current was held at or near 30 ma by the stabilizing bias circuit.

Without the stabilizing circuit, these so-called "compression" curves would be quite different. For instance, if the bias were held constant, we should expect that the gain would not drop as fast as indicated here, since the plate current would rise as the drive was increased.

At any rate, in an F.M. system, we are not concerned with how much

"static compression" exists, hut rather with how much gain can be realized without exceeding the dissipation ratings of the tuhes.

With this in mind data were taken on 25 of the experimental tuhes. In each case they were matched to the input and output waveguides and the cathode current was stahilized at 30 ma. After driving the tuhe to a high level of output power, the circuits were rematched and the resulting "compression" curves revealed the capabilities tahulated.

Table II
Summary of Data on 25 Experimental Close-Spaced Triodes

| | Highest | Lowest | Average |
|---|---|---|---|
| Low level gain | 12.3 db | 3.8 db | 7.8 db |
| Gain (500 mw output) | 7.0 db | −8.0 db | 1.82 db |
| Power Output (3 db gain) | 950 mw | 50 mw | 455 mw |

It can be seen from the tahle that we might expect to ohtain a gain of 20 or 25 dh with three or four stages with a power output of ahout 500 mw and a flat band of over 20 mc.

## Three Stage Amplifier

A three-stage amplifier with 24 db gain has heen assemhled using an earlier type of circuit and loop tested at low levels on the equipment of Messrs. A. C. Beck, N. J. Pierce and D. H. Ring.[5] This amplifier had a handwidth of about 30 mc to the 1 dh points and while it does not represent the best that can be done with the 416A tuhe, the results of the loop test are interesting.

The recirculating pulse test, or loop test, is performed on a repeater component to determine its ahility to reproduce a pulse faithfully after repeated transmissions. The output of the amplifier is connected to its input through a long delay line and an adjustable attenuator. The overall gain of the loop thus formed is adjusted to unity or zero dh so that an injected pulse will recirculate through the loop without attenuation but accumulating distortion with each round trip. After allowing the pulse to recirculate long enough the amplifier is hlanked out or quenched and the recirculating pulse amplitude dies out, thus preparing the loop forthe next injected pulse, when the process is repeated. With a pulse length of one microsecond and an overall delay of two microseconds, one hundred round trips occur in 0.2 milliseconds, thus allowing the process to he repeated at the rate of two or three thousand times per second. A cathode ray oscilloscope is used to examine the pulse shapes, and its sweep is synchronized to the injected pulse so that successive corresponding pulses are superposed, enahling the operator to examine the pulse after any

number of round trips or select individually the nth round trip for inspection.

Fig. 21(a) shows the complete cycle between successive injected pulses, and the individual pulses that follow cannot be resolved at this slow sweep speed. Fig. 21(b) shows the first 26 round trips resolved so that they are distinguishable. Figure 21(c) shows the first and second round trips

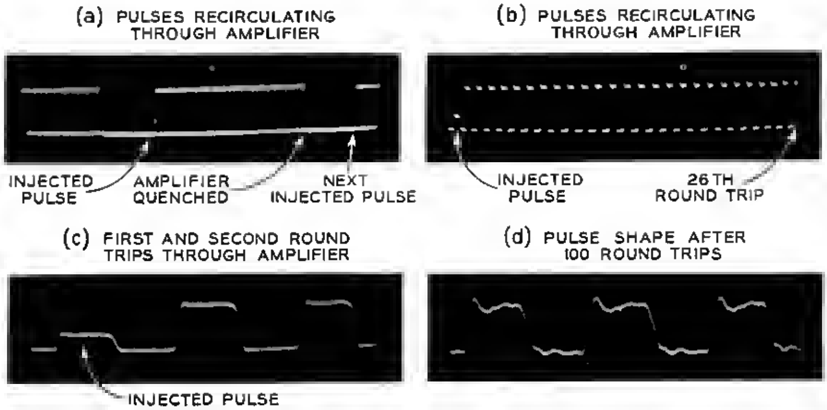


Fig. 21.—Recirculating pulse test patterns.

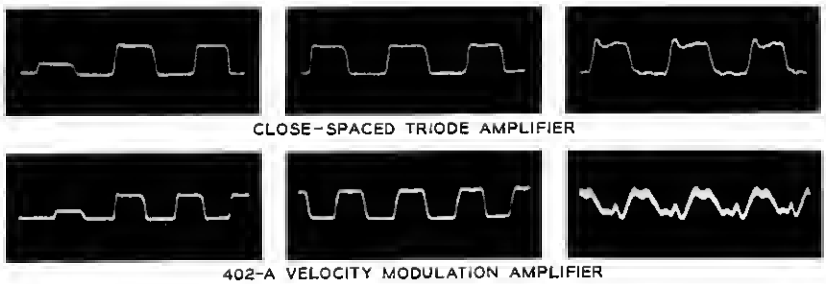


Fig. 22.—Recirculating pulse patterns showing 1st, 10th and 100th round trips for: Top: Close-spaced triode amplifier. Bottom: 402-A velocity modulation amplifier.

through the amplifier, with little or no distortion discernible. Fig. 21(d) gives, to the same scale as the preceding picture, the pulse shape after 100 round trips. A little overshoot and subsequent oscillation is now visible, although the whole pulse shape is still not too bad.

In Fig. 22, these results are compared with the results of a similar test performed on a four-stage, stagger tuned, stagger-damped amplifier using the 402 velocity variation amplifier tubes; the first, the tenth and the hundredth round trips are shown. Little or no distortion is seen at the

tenth round trip, but the superiority of tbe 416A amplifier is clearly shown in the hundredth round trip.

Both amplifiers were operating at low levels, and the pulse was an amplitude modulated one. Since these are not the conditions under which our microwave radio relay circuits operate, conclusions should not be drawn about how many repeater stations can now be put in tandem. The test merely indicates that an improvement has been made, thus corroborating the evidence obtained by otber tests.

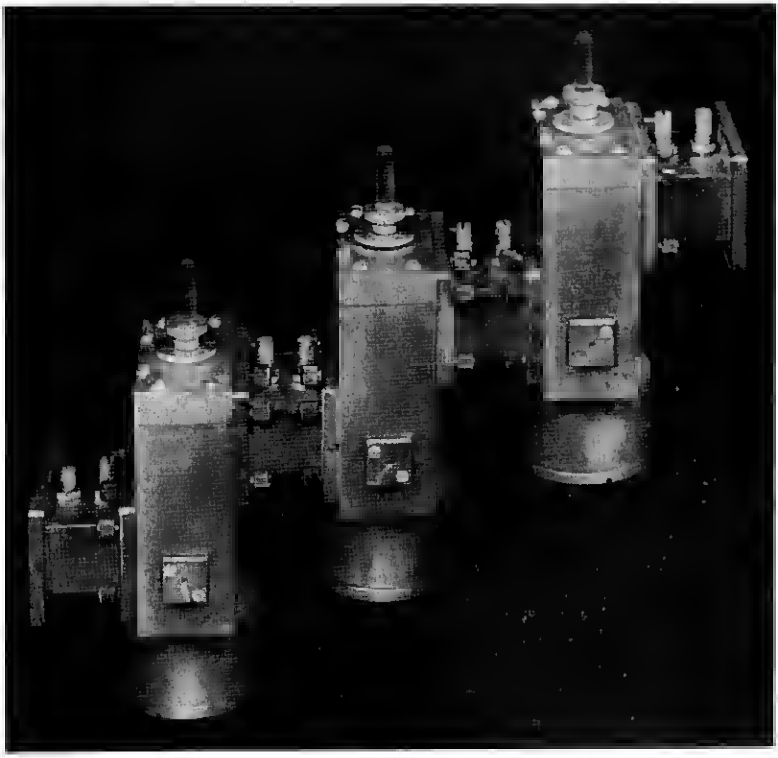

Fig. 23.—An assembled three-stage microwave amplifier.

Still further improvement has been made since loop testing the model ten amplifier. A tbree stage 416A amplifier (see Fig. 23) using model eleven circuits had comparable gain, 23 db, but a bandwidth of 50 mc to points 0.1 db down. These data again are for low level operation, but it is reasonable that half a watt might be expected from four such stages with comparable gain and slightly narrower bandwidth, surely 30 mc.

## Noise Figure

In a forward looking program it is well to keep in mind other possibilities for this tube, such as use in a straight through type of repeater in which all of the amplification is obtained at microwave frequencies. In such an application the noise figure of the triode becomes one of its limitations, since the 416A must compete with the low noise figure of the silicon crystal converter which, for the New York-Boston circuit, is around 14 db. Data on thirty five early experimental and production 416A tubes gave an average value of 18.08 db at 4060 mc.* Each of the

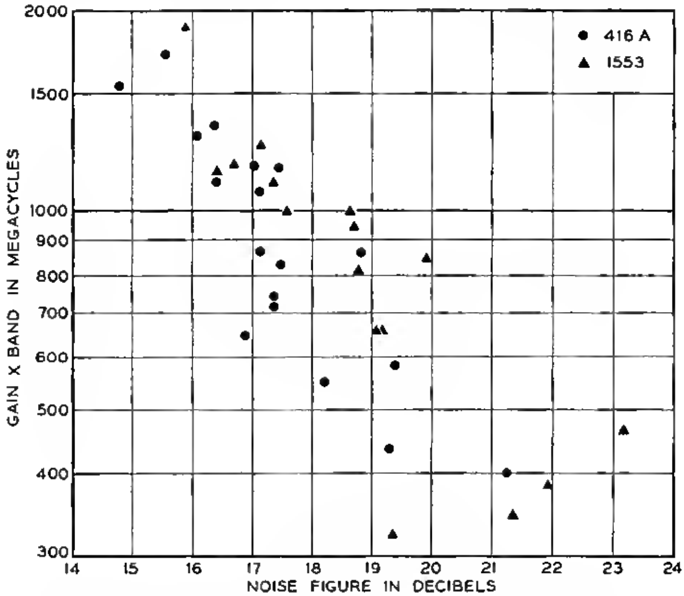


Fig. 24.—Noise figure vs gain-band product for close-spaced triode.

tubes was operated at 200 volts with 30 ma space current and was tuned so as to present matched impedances to the input and the output waveguides. The best of this batch had a noise figure of 14.79 db and the poorest 23.2 db. These measurements were made with a fluorescent light noise source.[6]

An interesting correlation between noise figure and gain-band product was uncovered during these tests, as can be seen in Fig. 24, which gives the noise figure in db on the abscissa and the gain-band product in mega-

* More recently, a sample of twelve production 416A tubes ranged from 13.5 to 16.2 db and averaged 15.06 db noise figure, with a standard deviation of 0.8 db.

cycles along the logarithmic ordinate. The points scatter between the extremes of 15 db noise figure for a gain-band product of 2000 megacycles to 23 db noise figure at 400 megacycles gain-band product. Extrapolating from these data, a noise figure of 10 db might be achieved if the gain-band product could be increased to 5500 mc. It is reasonable to expect that an improvement of this amount can be achieved if the resistance and return electron losses inside the tubes can be eliminated.[7]

We may use these data to determine the expected noise figure of a straight through amplifier, thus:

$$F = F_A + \frac{F_B - 1}{G_A} + \frac{F_C - 1}{G_A G_B} \cdots \tag{1}$$

If, for example, we assume that all stages are alike in noise figure and in gain, equation (1) approaches the expression, as the number of stages increases without limit:

$$F \underset{n \to \infty}{\overset{\lim}{=}} \frac{F_A G_A - 1}{G_A - 1} \tag{2}$$

Using an average value of 10 db gain per stage, the overall noise figure would be as follows:

(1) For $F_A = 30$ (best tube, 14.79 db)
$F = \frac{299}{9} = 33.2$ or 15.2 db

(2) For $F_a = 64$ (average tube, 18.08 db)
$F = \frac{639}{9} = 71$ or 18.5 db.

## Straight-Through Amplifier

The actual performance of a ten-stage amplifier was about what should be expected from the considerations above. The best tube ($10 \log F =$ 14.79 db) was used in the first stage, and the next best tube in the second stage. The measured overall noise figure was 15.96 db. The overall gain was 90 db and the band was flat to 0.1 db for 44 mc. Such an amplifier with its associated power supply and individual control panels is shown in Fig. 25.

## Conclusions

A circuit is described which lends itself readily to utilizing the 416A close-spaced triode as a modulator or a cascade amplifier for microwave repeaters operating at 4000 mc. Data are presented on early experimental models of the tube.

As modulators, single tubes had from 5 to 9 db gain with 10 to 20

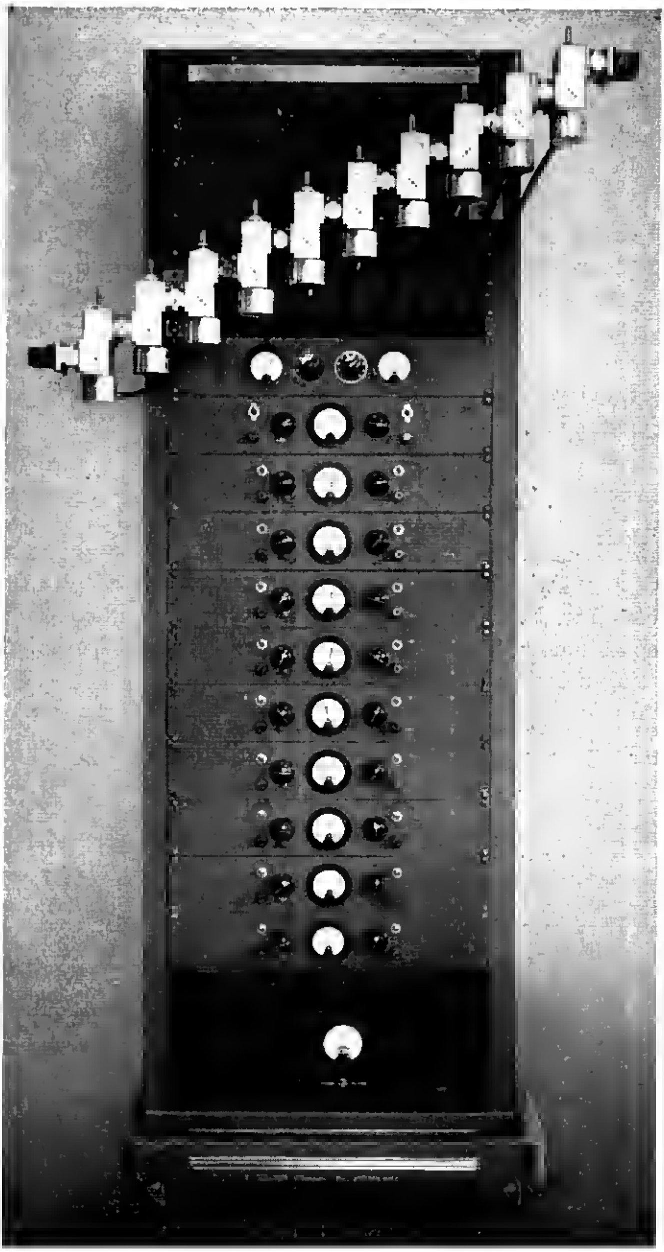

Fig. 25.—A ten-stage microwave amplifier operating at 4000 mc.

mw output when driven with 200 mw of beating oscillator power. A bandwidth of twenty megacycles was readily obtained.

As amplifiers at 4060 mc, the average gain of 60 tubes was 9 db, the average bandwidth of 34 tubes was 103 mc to the half power points, the average noise figure of 35 tubes was 18.08 db and the average power output (for 3 db gain) was 455 mw for 25 tubes. Operating the tubes in cascade produced an amplifier whicb had less distortion of pulse shape than an earlier amplifier which used tbe 402-A velocity variation tube. A ten-stage amplifier bas been assembled and tested, yielding 90 db gain, a noise figure (with selected tubes) of 15.96 db and a bandwidth of 44 mc to the 0.1 db points.

These data are for early experimental models of the tube and it is likely tbat subsequent alterations may improve tbe performance in tbe production models.

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